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OPTIMIZATION OF FIBER BASED DISPERSION COMPENSATION IN RZ AND NRZ DATA MODULATION FORMATS

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Abstract

In this paper, dispersion compensating fibers are used to compensate for the positive dispersion accumulated over the length of transmission fiber. Pre and post dispersion compensation schemes are employed for dispersion compensation. Modulation formats employed are RZ and NRZ. The performance of these systems is analyzed and then the optimization of these schemes is done by varying the input powers of single mode fibers and dispersion compensating fibers. The investigation is done on detailed simulative analysis.

Keywords: Dispersion compensating fibers, Compensation, Single mode fiber, Return and non return to zero modulation format, *Q* Factor.

1. Introduction

When optical signals are transmitted over optical links, different wavelength components of the optical signals will generally experience different propagation times due to the fact that the transport medium (such as an optical fiber) has different effective refractive indices for different wavelengths. This phenomenon is referred to as dispersion, or chromatic dispersion. As a result of dispersion, an optical pulse, which always has some finite width in wavelength, will be broadened, since different wavelength components of the pulse will travel at slightly different group velocities through the optical link. Such broadening of optical pulses caused by the dispersion may lead to a situation at the receiver end where it is difficult to separate adjacent pulses from each other during detection. Particularly for high modulation rate systems, dispersion becomes a severely limiting factor. For this reason, it is typically required to use some kind of dispersion compensation along the optical link and/or at the receiver side.

Nomenclatures

D_{DCF}	Dispersion of dispersion compensated fiber, ps/nm.km
D_{SMF}	Dispersion of single mode fiber, ps/nm.km
L_{DCF}	Length of dispersion compensated fiber, m
L_{SMF}	Length of single mode fiber, m
m	Modulation index
t_{rise}	Circuit rise time, s
V_{bias}	Effective dc bias voltage, V
V_{off}	Off state voltage ,V
V_{on}	On state voltage, V

Abbreviations

CATV	Cable television
CW	Continuous wave
DCF	Dispersion compensating fiber
DWDM	Dense wavelength division multiplexing
EDFA	Erbium doped fiber amplifier
LAN	Local area network
NRZ	Non return to zero
OOK	On-off keying
RZ	Return to zero
SMF	Single mode fiber
TDM	Time division multiplexing

2. Dispersion Compensation Schemes Employed

To support a high-capacity dense wavelength-division-multiplexing (DWDM) transmission, the embedded standard single-mode fiber (SMF) should be upgraded to overcome the dispersion limit. For this purpose, some dispersion compensation scheme must be employed periodically at the amplification stages [1]. There are several different methods that can be used to compensate for dispersion, including dispersion compensating fiber (DCF), chirped Bragg gratings and optical phase conjugation. In this paper, dispersion compensating fibers are used to compensate dispersion. The use of dispersion compensating fiber is an efficient way to upgrade installed links made of standard single mode fiber [2]. Conventional dispersion compensating fibers have a high negative dispersion -70 to -90 ps/nm.km and can be used to compensate the positive dispersion of transmission fiber in C and L bands. Spans made of SMF and DCF are good candidates as their high local dispersion is known to reduce the phase matching giving rise to four waves mixing in wavelength division multiplexing systems. Signal degradation in such systems is due to combined effects of group velocity dispersion, Kerr nonlinearity, and accumulation of amplified spontaneous emission noise due to periodic amplification. Because of the nonlinear nature of propagation, system performance depends on the power levels at the input of different types of fibers, on the position of the DCF [3] and on the amount of residual dispersion [4, 5].

Of particular interests are the pre-, post- and symmetrical compensation techniques where each link is made of spans where the DCF is located before, after the SMF or symmetrically across the SMF. A DCF module should have low insertion loss, low polarization mode dispersion and low optical nonlinearity. In addition to these characteristics, DCF should have large chromatic dispersion coefficient to minimize the size of a DCF module since DCF modules are generally mounted in a rack in a terminal office. However, there are design tradeoffs among chromatic dispersion, effective area and bending loss. Large chromatic dispersion coefficient gives small effective area and large bending loss.

By placing one DCF with negative dispersion after a SMF with positive dispersion, the net dispersion will be zero

$$D_{SMF} \times L_{SMF} = -D_{DCF} \times L_{DCF} \tag{1}$$

where D and L are the dispersion and length of each fiber segment, respectively.

Fiber based Compensation is done by three methods:

(i) Pre-Compensation
(ii) Post Compensation
(iii) Symmetrical Compensation

Pre-Compensation: The optical communication system is pre compensated by the dispersion compensating fiber of negative dispersion against the standard fiber. Post-Compensation: The optical communication system is post compensated by the dispersion compensating fiber of negative dispersion against the standard fiber. Symmetrical-Compensation: The optical communication system is symmetrically compensated by the dispersion compensating fiber of negative dispersion against the standard fiber.

3. Data Modulation Formats Used

An optical modulation format is the method used to impress data (i.e., information) on an optical carrier wave for transmission over optical fiber or any other any other media such as free space, nano photonic optical waveguide, etc. In single mode optical fibers, the optical field has three physical attributes that can be used to carry information: intensity, phase (or frequency) and polarization. Depending upon which of the three quantitative is used for information transport, we distinguish between intensity, phase (or frequency) and polarization data modulation formats. This classification does not require a phase modulated optical field to be constant envelope, nor an intensity modulated field to have constant phase. It is the physical quantity used to convey data information that drives the classification.

The simplest optical modulation format is on-off keying (OOK) intensity modulation, which can take either of two forms: non return to zero (NRZ) or return to zero. The advantages of using NRZ data modulation formats include its low electrical bandwidth requirement, insensitivity to laser phase noise and simplest configuration of transceivers. The reduced spectrum width improves the dispersion tolerance but it has the effect of intersymbol interference between the pulses this modulation format is not suitable when high bit rates and distance are considered.

In the NRZ format the function that describes the voltage pulse is given by:

$$\left.\begin{aligned} V(t) &= V_{on-off}\left[1-\exp(-t/t_{rise})^2\right], & V_m &= V_{on} \\ V(t) &= V_{on-off}\left[\exp(-t/t_{rise})^2\right], & V_m &= V_{off} \end{aligned}\right\} \quad (2)$$

where $V_{on\text{-}off}$ = V_{on} – V_{off} = $-2mV_{bias}$ and t_{rise} is the circuit rise time that determines the 3dB modulation bandwidth BW. In return-to-zero (RZ) modulation format, power is transmitted only for a fraction of the bit period.

It has become a popular solution for ultra-long-haul 10Gbps and long-haul 40Gbps because it has a higher peak power, a higher signal-to-noise ratio, and lower bit error rate than non-return-to-zero (NRZ) encoding. It also offers better immunity to fiber nonlinear effects, polarization-mode dispersion and the interaction effects between DWDM channels, such as cross-phase modulation. RZ modulation is very similar to the NRZ modulation format with respect to the function that describes the voltage pulse. However, the transmitter rise time is required to be less than 35% of the bit interval which is less than 70 % of the bit interval in case of NRZ modulation format. RZ modulation has become a popular solution for 10 Gbit/s systems because it has a higher peak power, a higher signal-to-noise ratio, and lower bit error rate that NRZ encoding [6].

4. System Set up and Simulation Details

The transmitter section consists of data source, modulator driver (NRZ/RZ driver), laser source (lorentzian laser) and amplitude modulator. Data source produces a pseudo-random sequence of bits at a rate of 10 Gbit/s. The output of data source is given to modulator driver which produces NRZ/RZ format pulse with duty cycle of 0.5. The output of laser source is CW Lorentizan type. The line-width was set to 10 MHz full width half maximum. The modulator is of amplitude modulator type which has $\sin^2$ shaped input-output characteristics. Each span consists of 100 km of transmission fiber (SMF) and 20 km DCF in order to fully compensate for the dispersion slope and accumulated dispersion in the transmission fiber. The input powers of transmission fiber and DCF are varied independently from each other to find the maximum reach limit. Two EDFAs in front of transmission fiber and DCF with 4.5 dB noise figure each are used to adjust input power levels. At the receiver side, the optical signal is transformed in to an electrical signal by a PIN photodiode. The electrical signal is filtered by a low pass Bessel filter with -3dB bandwidth of 8 GHz. The simulation set ups for pre and post compensation schemes are as shown in Figs. 1 and 2.

The length of dispersion compensated fiber is taken as 20 km and that of single mode fiber is taken as 100 km and EDFAs with 4.5 dB noise figure are used and these are modeled by wavelength independent gain and noise addition. Sequence lengths of 10^7 bits are used to obtain realistic Q factor values at the receiver. The calculation of propagation in optical fibers is performed by standard split step algorithm with adaptive step size. In the algorithm both the dispersion and non linearity is assumed to be varied over small step size independently. The simulation is done with optsim software which is an advanced optical communication system simulation package designed for professional engineering and cutting-edge study of WDM, DWDM, TDM, CATV, optical LAN, parallel optical bus, and other emerging optical systems in telecom, data communication, and other applications.

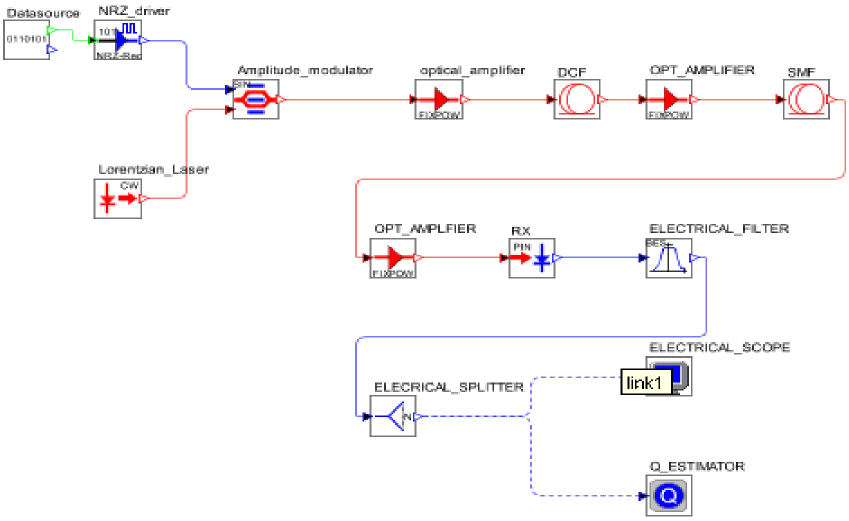


Fig. 1. Schematic for Pre Compensation Scheme.

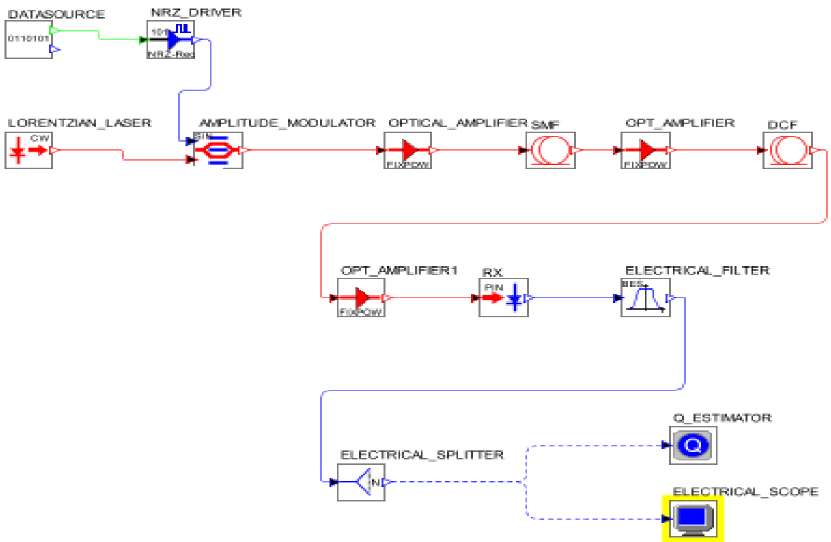
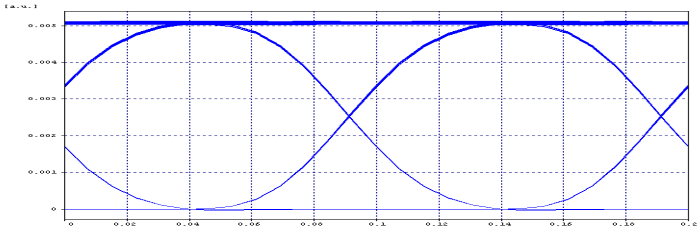


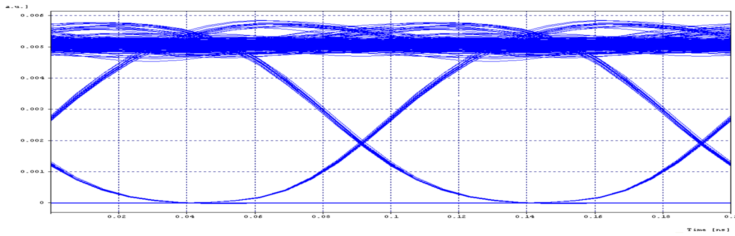
Fig. 2. Schematic for Post Compensation Scheme.

5. Results And Discussions

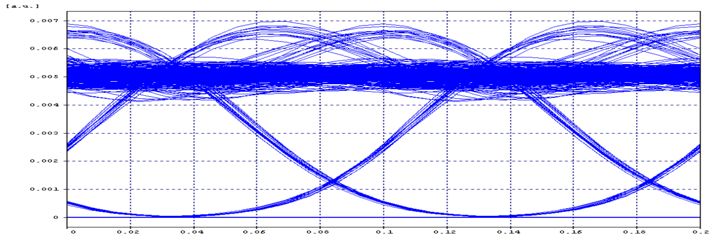
The results of the set ups are analyzed by observing the eye diagrams of the received signals and by obtaining the contour plots for different number of spans. The eye diagrams for the two compensation methods namely pre compensation and post compensation in RZ and NRZ transmission systems are shown in Figs. 3 to 6. As observed from the eye diagrams pre compensation scheme is slightly better than post compensation scheme because of wider eye opening. Pre compensation decreases the signal power faster than post compensation due to higher attenuation of DCF.



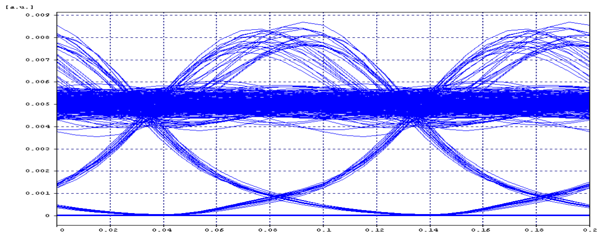
(a) Transmitted NRZ Modulation Format.



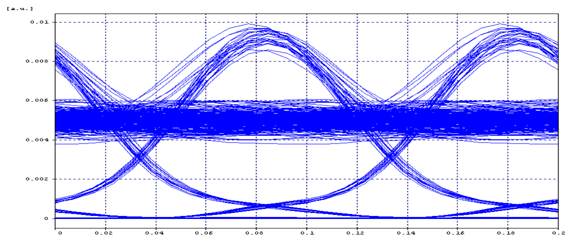
(b) Received NRZ Modulation Format after 2 Spans.



(c) Received NRZ Modulation Format after 5 Spans.

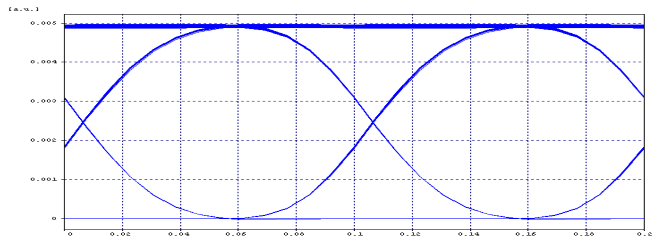


(d) Received NRZ Modulation Format after 10 Spans.

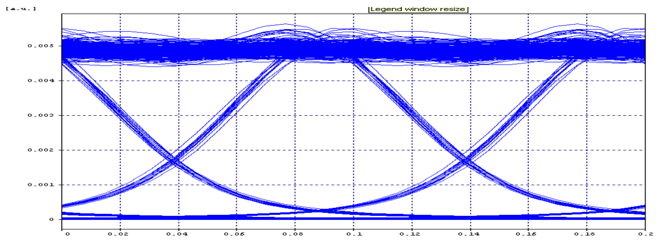


(e) Received NRZ Modulation Format after 15 Spans.

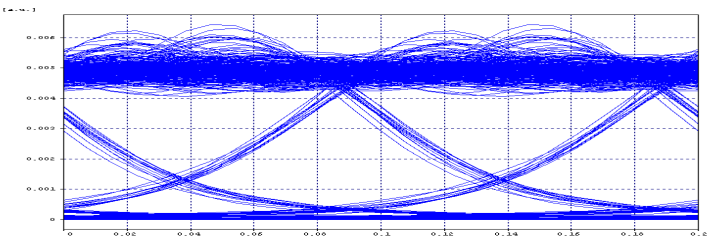
Fig. 3. Eye Diagrams of Transmitted and Received NRZ Modulation Format (Pre Compensated).



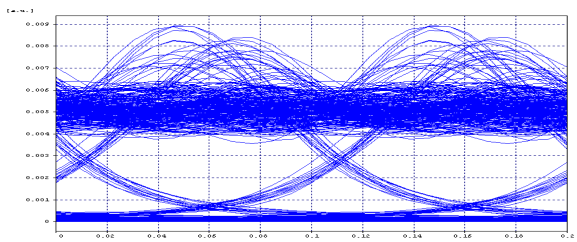
(a) Transmitted NRZ Modulation Format.



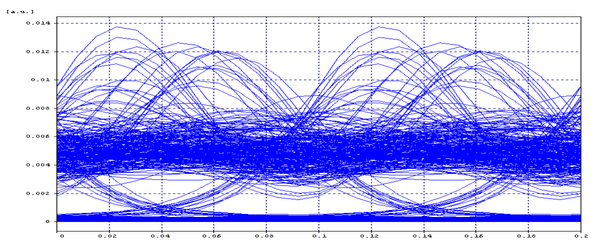
(b) Received NRZ Modulation Format after 2 Spans.



(c) Received NRZ Modulation Format after 5 Spans.

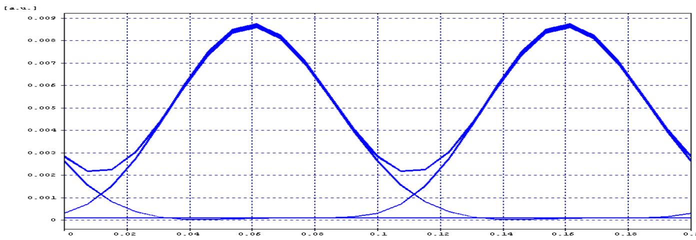


(d) Received NRZ Modulation Format after 10 Spans.

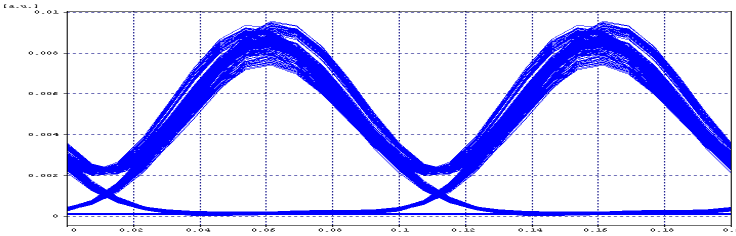


(e) Received NRZ Modulation Format after 15 Spans.

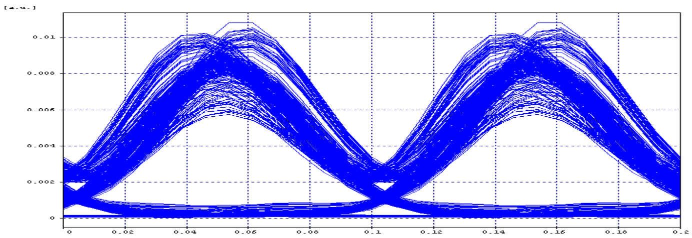
Fig. 4. Eye Diagram of Transmitted and Received NRZ Modulation Format (Post Compensated).



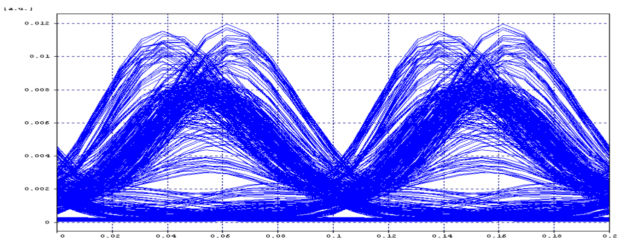
(a) Transmitted RZ Modulation Format.



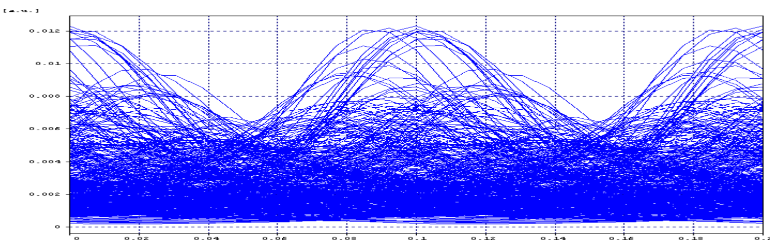
(b) Received RZ Modulation Format after 2 Spans.



(c) Received RZ Modulation Format after 5 Spans.

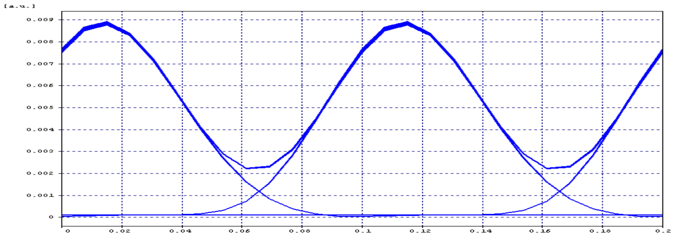


(d) Received RZ Modulation Format after 10 Spans.

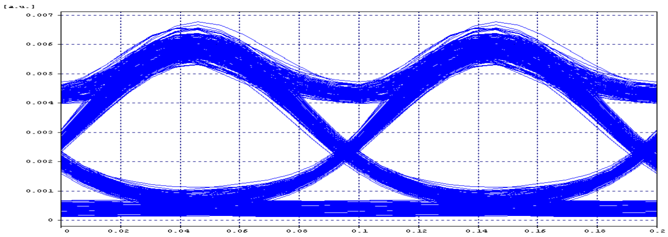


(e) Received RZ Modulation Format after 15 Spans.

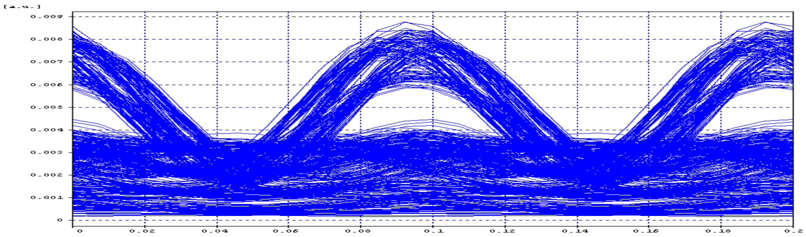
Fig. 5. Eye Diagram of Transmitted and Received RZ Modulation Format (Pre Compensated).



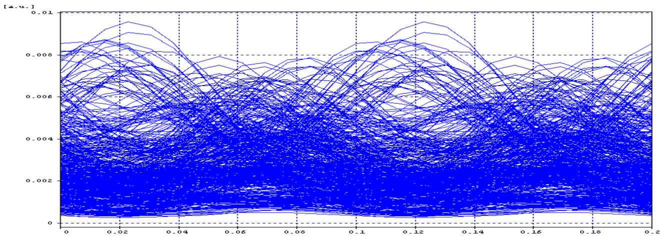
(a) Transmitted RZ Modulation Format.



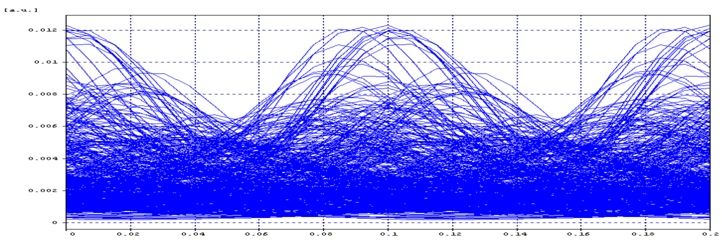
(b) Received RZ Modulation Format after 2 Spans.



(c) Received RZ Modulation Format after 5 Spans.



(d) Received RZ Modulation Format after 10 Spans.

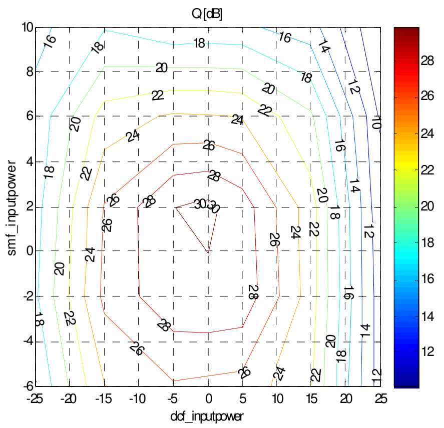


(e) Received RZ Modulation Format after 15 Spans.

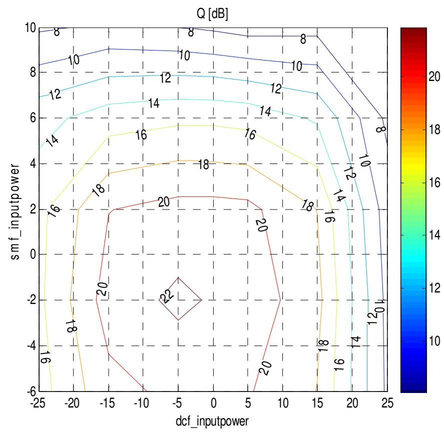
Fig. 6. Eye Diagram of Transmitted and Received RZ Modulation Format (Post Compensated).

After this, optimization of pre and post compensation schemes is done. For 100% dispersion compensation, the powers at the SMF input and DCF input were varied systematically by varying the gains of EDFAs and *Q* factor was calculated for each set of power after a defined number of cascaded spans. Average signal input powers between -6 to 10 dBm into SMF and -25 to +25 dBm into DCF were evaluated. Figures 7 to 10 show *Q* factor contour plots obtained after 2, 5, 10, 15 cascaded spans for 100% pre and post dispersion compensation schemes for NRZ and RZ modulation formats. RZ modulation format considered in this study corresponds to 50% duty cycle. Transmission optimum should exist at a particular level of power into DCF and power into SMF which is clearly observed in the contour plots obtained for different number of spans. The results are obtained for values of *Q* greater than 15.

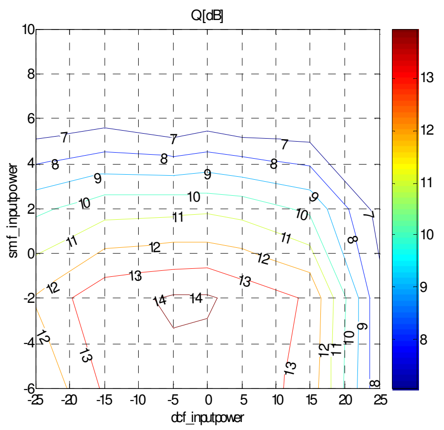
Results are plotted in Fig. 11 showing the *Q* factor value corresponding to pre and post dispersion compensation schemes for NRZ and RZ data modulation formats for the indicated number of 120 km fiber spans.



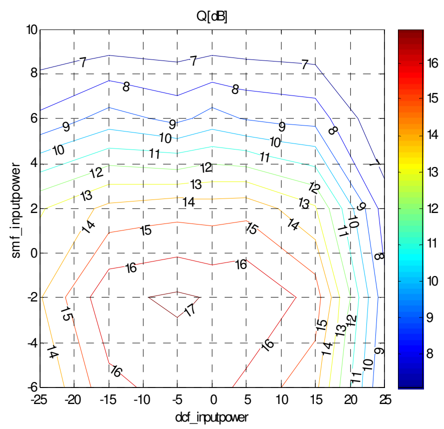
(a) 2 Cascades.



(b) 5 Cascades.

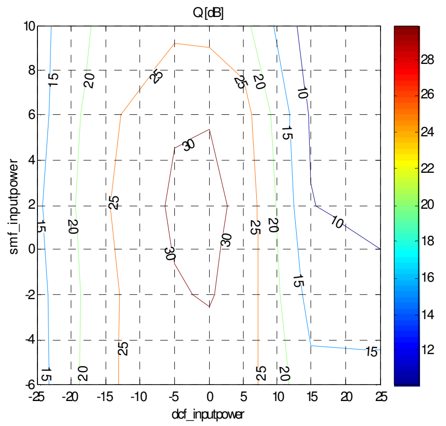


(c) 10 Cascades.

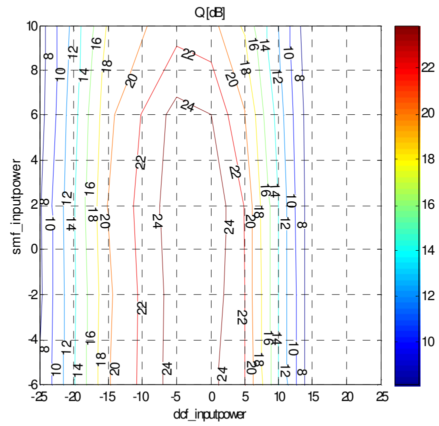


(d) 15 Cascades.

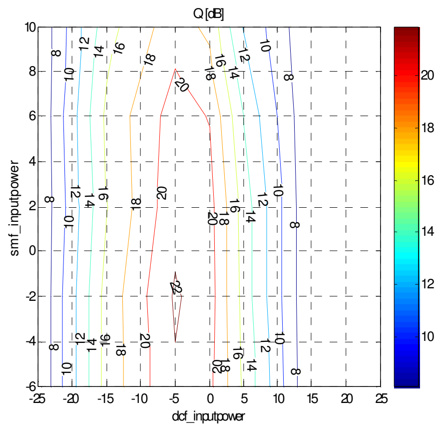
Fig. 7. Contour Plot showing Evolution of *Q* Factor as a Function of SMF and DCF Input Powers for Pre Compensated NRZ Transmission System.



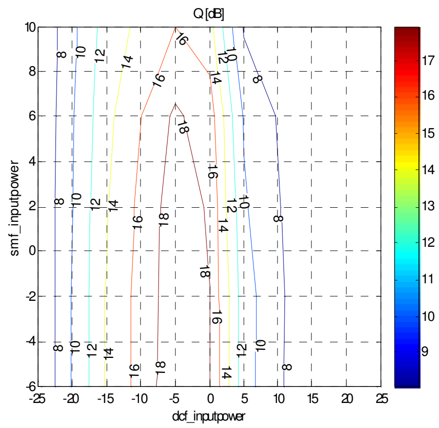
(a) 2 Cascades.



(b) 5 Cascades.

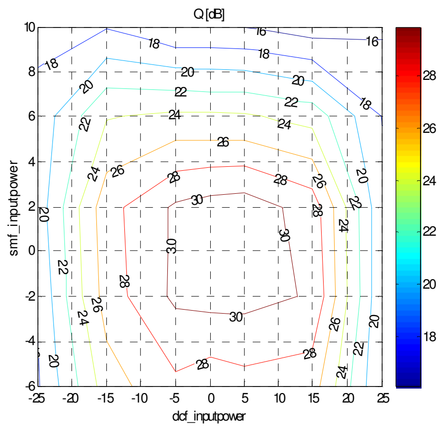


(c) 10 Cascades.

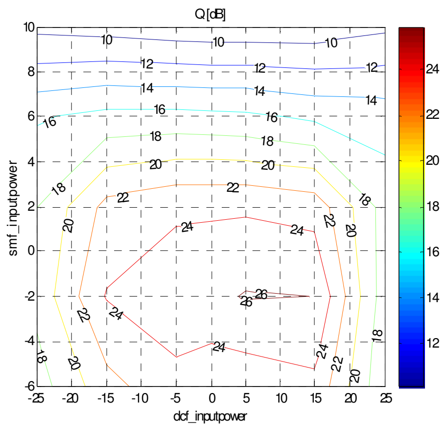


(d) 15 Cascades.

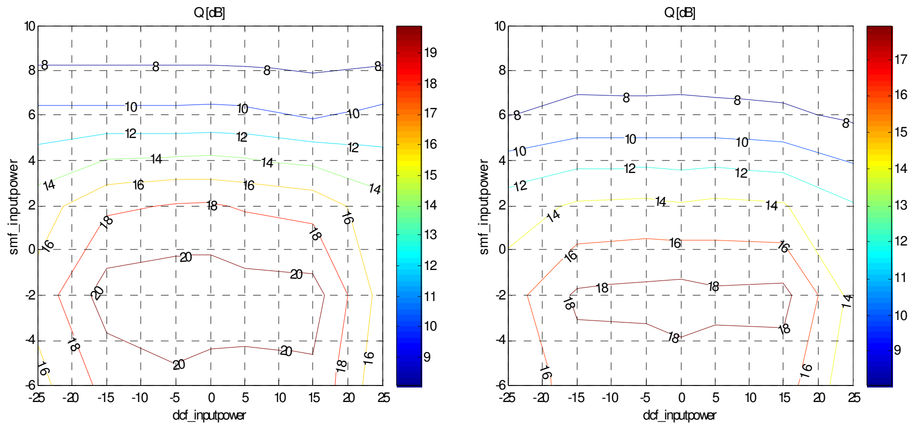
Fig. 8. Contour Plot showing Evolution of *Q* Factor as a Function of SMF and DCF Input Powers for Post Compensated NRZ Transmission System.



(a) 2 Cascades.

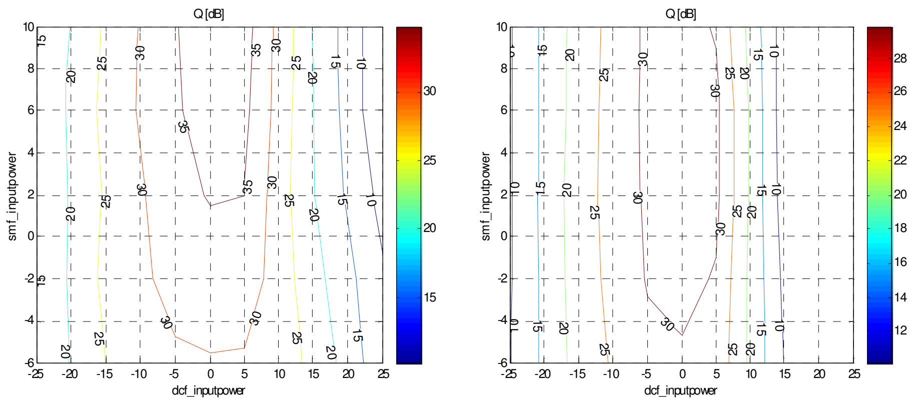


(b) 5 Cascades.

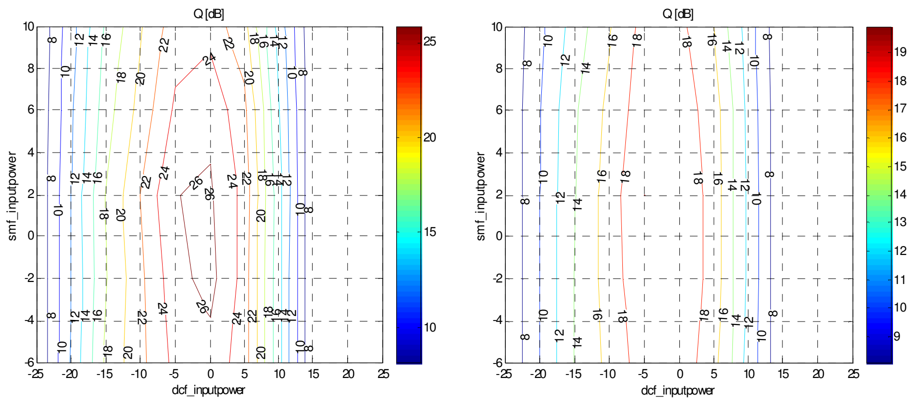


(c) 10 Cascades. **(d) 15 Cascades.**

Fig. 9. Contour Plot showing Evolution of *Q* Factor as a Function of SMF and DCF Input Powers for Pre Compensated RZ Transmission System.



(a) 2 Cascades. **(b) 5 Cascades.**



(c) 10 Cascades. **(d) 15 Cascades.**

Fig. 10. Contour Plot showing Evolution of *Q* Factor as a Function of SMF and DCF Input Powers for Post Compensated RZ Transmission System.

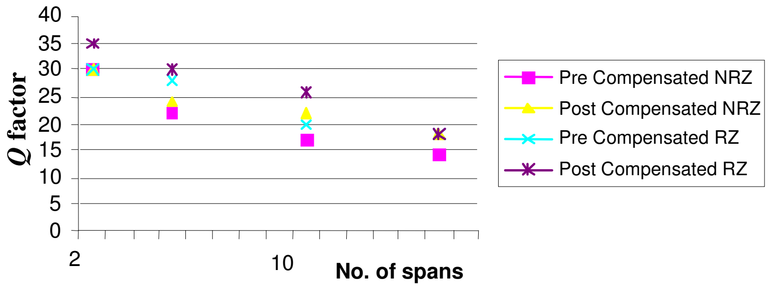


Fig. 11. Graph showing Variation of *Q* Factor vs. Number of Spans.

6. Conclusions

In this paper, two basic modulation formats RZ and NRZ are investigated in a repeatered 10 Gbit/s dispersion managed system based on 120 km fiber spans. Dispersion Compensation schemes employed were pre and post dispersion compensation schemes. Input power levels of SMF are DCF are optimized. Existence of transmission optimum is clearly observed from contour plots.

After optimizing pre and post dispersion compensation schemes, RZ modulation format is better as compared to NRZ data modulation format. *Q* factor obtained in RZ transmission system is more as compared to NRZ transmission systems corresponding to two, five, ten and fifteen 120 km fiber spans.

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